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(54) A method and apparatus for controlling a tractor/implement combination

(57) In the field of tractor/implement control, there is a need for accurate, real-time data on the true draught force generated by engagement of an implement (60) with the ground.

A method of controlling a tractor/implement combination (10) includes obtaining and storing calibration data on the torque generated at the tractor flywheel, while the implement (60) is disengaged from the ground. Such data includes the rolling resistance and frictional/parasitic losses between the flywheel and driven wheel axle of the tractor.

During subsequent operation of the tractor/implement combination, the calibration data are subtracted from instantaneous torque data to generate a signal indicative of the implement draught force.

The draught force signal may be factored to take account of the tractor powertrain ratio and the rolling radius of the tractor tyres.

The method allows generation of accurate draught force data, regardless of the nature and mounting location of the implement (60).

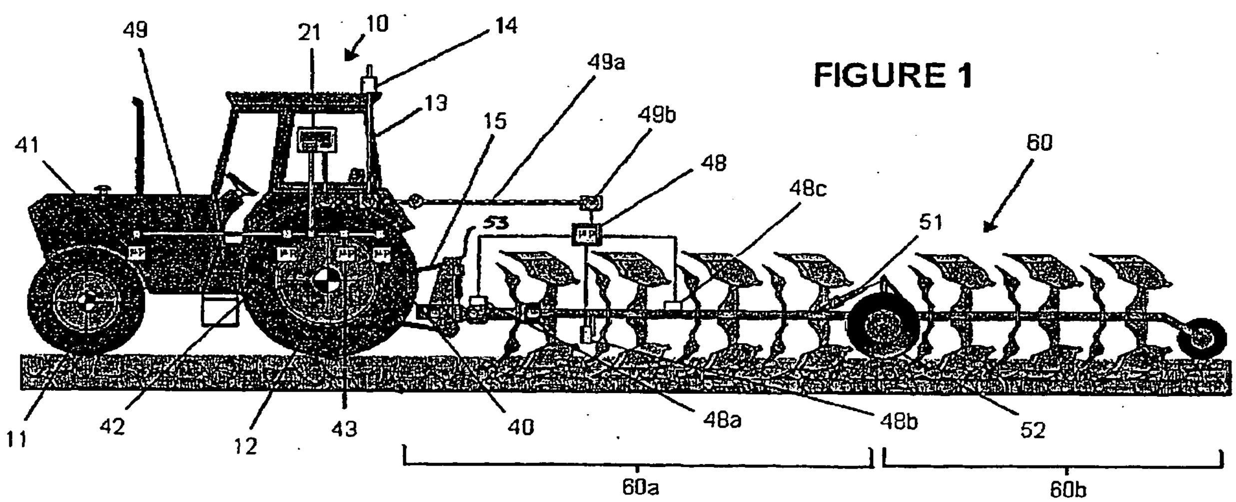

FIGURE 1

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Description

[0001] This invention relates to a method and apparatus for controlling a tractor/implement combination.

[0002] By "tractor" is meant any vehicle capable of propelling a ground or soil engaging implement for the purpose of processing the ground or soil, or objects (eg. crops, forage) lying on or in the ground or soil.

[0003] Typically a tractor is a four wheel drive vehicle having a hitch for attachment of an implement behind the vehicle. It is also well known for tractors to push implements, such as furrow presses.

[0004] The typical configuration of a tractor includes an operator cab mounted at the rear of the vehicle, and a forward-mounted engine and transmission system. However, it is also known to provide a multi-purpose vehicle, that may function as a tractor, having a forward mounted cab and underslung engine and transmission systems beneath a load carrying deck.

[0005] Other forms of tractors include two wheeled, two wheel drive devices and tracked vehicles that may be coupled to pull or push implements.

[0006] The invention relates to and embraces within its scope all such tractors.

[0007] Tractor/implement combinations are widely used in various processes in agriculture. One of the most common of these is ploughing, in which a plough is towed behind a tractor. However, tractors may be used for a great variety of other operations such as spraying, furrow pressing, harrowing, raking, seeding and a number of specialised operations such as arise eg. in vineyards and estuaries, in which specially designed ground-engaging implements are used.

[0008] Consequently, "implement" as used herein includes but is not limited to ploughs, harrows, furrow presses, rakes, seed drills, and indeed virtually any article that may be attached to or operated by a tractor and that has the effect of increasing the energy demand of the tractor by virtue of engagement of the implement with the ground or soil or with objects thereon or therein.

[0009] Electronic control of the subsystems of tractors is becoming more and more common. For example EP-A-0.838.141 (the entire disclosure of which is incorporated herein be reference) discloses an integrated control system for tractors (designated by the trade mark "TICS" that is the subject of Community Trade Mark application no. 1532696), by means of which a programmed microprocessor (or series of microprocessors) maximises the workrate of a tractor eg. during ploughing operations, by comparing the implement draught force against a steady state reference model, and performing implement working width and transmission ratio adjustments in order to maintain a maximal workrate while also maintaining a predetermined implement working depth.

[0010] The method and apparatus of EP-A-0.838.141 is most effective when it is possible to obtain an accurate, real time indication of the proportion of the tractor engine output that is attributable to the implement draught force; and the proportion that is attributable to other losses.

[0011] One way of generating a signal indicative of the implement draught force is to provide a draught force sensing pin (including eg. a strain gauge forming part of a *per se* known bridge circuit) in the lower link of the tractor three point hitch.

[0012] The accuracy of the signal generated from such a sensing pin is acceptable when the implement is a fully-mounted one such as a fully-mounted plough.

[0013] The accuracy of the draught force sensing pin arrangement is worse for semi-mounted implements such as a semi-mounted plough; and of no use whatsoever with trailed or pushed equipment, that does not place a load on the lower link of the tractor three point hitch.

[0014] EP-A-0.741.286 (the entire disclosure of which is incorporated herein by reference) discloses one form of a torque sensor securable to or constituting part of the flywheel of a tractor engine.

[0015] An arrangement such as that disclosed in EP-A-0.741.286, that generates a signal indicative of the flywheel torque, is more suitable than the above-mentioned lower link pin sensor, for control systems controlling a tractor/implement combination, since the engine loading "seen" by the flywheel torque sensor is a total loading value, regardless of whether the implement is trailed, semi-mounted, fully-mounted or propelled in some other way (such as pushed in front of the tractor instead of towed behind the tractor).

[0016] However, the generated torque signal is dependent upon the selected tractor transmission ratio and tyre circumference (or the effective circumference of another driven, ground engaging member if present). Also, the tractor flywheel torque is dependent upon both the implement-imposed drive line load (that tractor/implement control software may seek to maintain constant); and vehicle rolling resistance (RR) and frictional/parasitic losses in the tractor transmission and drive line.

[0017] It is possible to devise software in a tractor/implement control system that compensates for variations in the flywheel torque signal arising from the choice of tyre circumference and the selected transmission ratio. The compensations needed to account for these variations are likely to be invariant, and may be dealt with in the software algorithm by means of a simple factoring by memory-stored values relating to tyre size and transmission ratio.

[0018] On the other hand the vehicle rolling resistance and frictional/parasitic losses are unlikely to remain constant during operation of the tractor. The rolling resistance component of the flywheel torque is significant, accounting for

up to 25% of the flywheel torque.

[0019] According to a first aspect of the invention there is provided a method according to Claim 1.

[0020] The method of Claim 1 advantageously provides for the storing of calibration data indicative of the rolling resistance and frictional/parasitic losses acquired when the tractor/implement combination operates in a particular field condition. The stored rolling resistance and frictional/parasitic loss value may then be subtracted from the real time flywheel torque sensor output signal during use of the tractor in the said field in order to give an accurate indication of the engine loading due to the implement draught. The resulting, corrected torque signal may then be used in software and apparatus eg. as disclosed in EP-A-0.838.141 as a measure of the implement draught load.

[0021] In practice the tractor includes more than one transmission ratio, in which case the method includes the step of Claim 2. This step is advantageous because the draught force varies with changes in transmission ratio.

[0022] Even more preferably, therefore, the method of the invention includes the step of Claim 3, whereby calibration data are obtainable for more than two transmission ratios.

[0023] Consequentially the method of the invention permits a control method and apparatus, which may be as disclosed in EP-A-0.838.141, to operate with greater accuracy and efficiency.

[0024] Preferably the method includes the additional step of Claim 4; and/or the additional step of Claim 5.

[0025] These steps are preferred methods allowing for calculation of the draught force notwithstanding variations in the torque loading caused by the choice of tractor tyre (or other driven, ground engaging member) effective circumference and the overall transmission ratio between the tractor engine flywheel and the driven ground engaging member, respectively.

[0026] In a preferred embodiment of the invention the rolling radius and overall transmission ratio data are stored as one or more lookup tables in a memory forming part of or operatively connected to a control device such as a microprocessor.

[0027] In a particularly preferred embodiment of the method of the invention, the implement draught force signal may be employed to initiate or augment a control operation as defined in Claim 6.

[0028] More specifically, the implement draught force signal is calculated according to the formula:

$$\text{Implement Draught (kN)} = \frac{\begin{bmatrix}\text{Instantaneous Flywheel} - \text{Calibration Flywheel} \\ \text{Torque (N.m)} \qquad\qquad \text{Torque (N.m)}\end{bmatrix} \text{x PR}}{\text{Rear Tyre Rolling Radius (m)} \text{ x } 1000} \qquad \ldots(1)$$

Wherein :

PR = The tractor powertrain ratio, ie. the transmission and entire driveline ratio from the flywheel to the axle end;
Instantaneous Flywheel Torque = "Uncorrected Flywheel Torque"; and
Calibration Flywheel Torque = Transmission gear-specific flywheel torque value derived during a "Rolling Resistance" Calibration Procedure.

More specifically, maintenance of a generally constant implement depth value may be achieved by carrying out a control operation including adjusting or maintaining one or more variable subsystems as defined in Claim 8.

[0029] Of the five possible adjustment or maintenance operations defined in Claim 8, maintaining or adjusting the selected tractor transmission ratio, increasing the engine power output and maintaining the implement working depth have been found to provide highly efficient tractor/implement operation.

[0030] Conveniently the step of detecting the torque at the tractor engine flywheel and generating a signal indicative thereof, while the tractor/implement combination advances across the surface with a first tractor transmission ratio selected, takes place with the tractor engine governor set at approximately a "full throttle" setting as defined in Claim 9. Carrying out the calibration of the tractor/implement combination with the tractor operating at a full throttle setting advantageously avoids the need to compensate the flywheel torque value for variations in the governor setting.

[0031] Alternatively, it is possible to carry out the step of detecting the torque at the tractor engine flywheel and generating a signal indicative thereof while the tractor/implement combination advances across a surface with the implement disengaged from the surface, at a throttle setting less than maximum. Under such circumstances the method includes the step defined in Claim 10, whereby the calibration of the tractor/implement combination is normalised to a reference or datum throttle setting, that in practical embodiments is equivalent to a full throttle setting.

[0032] Preferably the method is as defined in Claim 11. This aspect of the method is advantageous when the tractor includes a so-called "power shift" automatic transmission. A power shift automatic transmission is one that carries out transmission shifts while the engine is under load. During such transmission shifts the torque at the engine flywheel

momentarily increases significantly. Such momentary increases in torque values would provide inaccurate data for control software carrying out the method of the invention. The method therefore provides more accurate control of the tractor/implement combination if the method is temporarily interrupted during transmission shifts.

[0033] Conveniently the method is as claimed in Claim 12; and optionally as claimed in Claim 13. These optional aspects of the method allow accurate control of the tractor/implement combination in sloping fields.

[0034] According to a second aspect of the invention there is provided a tractor/implement combination as defined in Claim 14. The apparatus of Claim 14 is advantageously suited to carrying out the method of Claims 1 to 13. The flywheel torque sensor defined in Claim 14 advantageously operates in the manner disclosed in EP-A-0.741.286.

[0035] Conveniently, the tractor/implement combination is as claimed in Claim 15.

[0036] Optionally the combination also includes a sensor for detecting the selected tractor transmission ratio and generating a signal indicative thereof, the processor optionally or additionally being programmed to compensate the value of the corrected flywheel torque signal for variations arising from the transmission ratio selected. These features of the apparatus of the invention advantageously permit carrying out of the method steps of Claims 2 and 3.

[0037] Preferably the processor is programmed to carry out a method as defined in any of Claims 1 to 13.

[0038] In particularly preferred embodiments the tractor/implement combination includes an actuator as defined in Claim 18; and/or an actuator as defined in Claim 19. These features advantageously permit adjustment and/or maintenance of the implement working depth and the tractor transmission ratio in order to maximise tractor/implement combination workrate while maintaining an optimal implement draught, as is the object of the method disclosed in detail in EP-A-0.838.141.

[0039] Also advantageously, the tractor/implement combination of the invention may optionally include a plurality of further sensors as defined in Claim 20. The further sensors also assist in carrying out a method as defined in EP-A-0.838.141.

[0040] Preferably the memory of the tractor/implement combination includes stored therein a steady state reference model; and the processor is programmed as defined in Claim 21. This feature also advantageously allows the tractor/implement combination efficiently to carry out a method as defined in EP-A-0.838.141.

[0041] The tractor/implement combination preferably is as defined in Claim 22, whose features conveniently allow practising of the method steps of Claim 13.

[0042] When the implement is a semi-mounted implement, such as a semi-mounted plough, that is towed behind a tractor, a further problem arises in that it is difficult efficiently to control the tractor wheelslip. Many modern agricultural tractors include a wheelslip limitation feature, in which a non-contact sensor eg. a Doppler radar sensor measures the true forward speed of the vehicle. A transmission-mounted sensor provides axle and therefore wheel speed. The control microprocessor of the tractor calculates the degree of wheelslip by subtracting the true vehicle speed value from a theoretical value simply derived from the wheel speed. If the degree of wheelslip exceeds an operator inputted or software imposed limit, control software may operate an actuator in order to reduce wheelslip to within acceptable limits. This ensures an efficient tractive effort and assists in maximising workrate of the tractor/implement combination. Commonly the actuator that operates to reduce wheelslip raises the three point hitch of the tractor, in an attempt to reduce the implement draught force and consequently reduce wheelslip. Raising the implement slightly also increases the implement to tractor weight transfer. The two factors combined may reduce wheelslip to an acceptable level.

[0043] However, in the case of semi-mounted implements the action of raising the implement hitch raises only the front of the implement. The working depth of the rear section of the implement is controlled by a mid-axle mounted wheel, mounted on an actuator strut whose length is adjustable by means of an hydraulic remote service valve.

[0044] According to a third aspect of the invention there is a provided a method as defined in Claim 23. This method raises two parts (typically the front and rear) of a semi-mounted implement such as a semi-mounted plough. This has the following advantages:

- The change in implement draught force resulting from the raising operations, that in turn reduces the tractor wheelslip, is less pronounced. Consequently the acceleration/deceleration of the massive tractor/implement combination is less than in the prior art, with the result that the efficiency of the tractor/implement combination operation is greater; and
- The method more accurately takes account of the proportion of the implement draught load that arises from the rear portion of the implement, resulting in a less pronounced reduction of the working depth of the front portion of the plough ie. a more even, less extreme reduction of the working depth of the entire plough.

[0045] Preferably the step of raising the second part of the implement is carried out according to an open loop algorithm as defined in Claim 24.

[0046] More specifically, the step of raising the second part of the implement is as defined in Claim 25. The Claim 25 step may be repeated a sufficient number of times to reduce the detected wheel slip to within an acceptable (operator or software defined) limit.

[0047] In preferred embodiments the remote mounting is as defined in Claim 26, whereby the step of raising the said mounting includes lengthening the actuator. This allows carrying out of the method following only minor modification of a prior art design of a semi-mounted implement.

[0048] Optionally the method includes the step (v) defined in Claim 27. The step (v) conveniently allows reestablishment of a preferred, optimum implement draught level following reduction of tractor wheelslip to within an acceptable limit.

[0049] Thus a control system such as defined in EP-A-0.838.141 may advantageously incorporate the method of Claim 27.

[0050] More preferably the length adjustable actuator includes a fluid actuator as defined in Claim 28, whereby the step of lowering the second portion of the semi-mounted implement includes exhausting fluid from the actuator via the spool valve.

[0051] According to a fourth aspect of the invention there is defined a tractor/implement combination as defined in Claim 29. The combination of Claim 29 is advantageously suited to carrying out a method as defined in any of Claims 23 to 28.

[0052] There now follows a description of preferred embodiments of the invention, by way of non-limiting example, with reference being made to the accompanying drawings in which:

Figure 1 is a schematic representation of a tractor/implement combination according to the invention; and
Figure 2 is a flow chart showing the steps of a first aspect of the method of the invention.

[0053] Referring to the drawings, there is shown an agricultural tractor denoted by the reference numeral 10. In common with such vehicles in use nowadays, tractor 10 has a plurality of driven, ground engaging members in the form of front 11 and rear 12 pairs of driven wheels, although as noted herein other kinds of tractors, including those that do not include four driven wheels and/or a rear mounted operator cab, are within the scope of the invention. As an example of another kind of tractor there are known vehicles in which one or both the pairs of driven wheels are substituted by sets of caterpillar tracks. Such tractors are within the scope of the invention. Tractor 10 also has an engine (not shown in the drawings), a transmission system including a gearbox, transfer box and appropriate differentials for the driven wheels; an operator cab 13 and a three point hitch 15 at the rear of the vehicle between the rear wheels for attachment of an adjustable implement, which in the embodiment shown is a plough 60.

[0054] Thus the tractor/implement combination 10 may be regarded as comprising a plurality of controllable subsystems, each of which influences the performance of the tractor in dependence on the prevailing conditions. The subsystems include the engine (adjustable in one of two ways, ie. by means of a throttle setting or by means of an engine governor setting, depending on the engine type); the transmission (adjustable by virtue of selection of gear ratios); the three point hitch 15; and the plough 60 adjustable in a manner described below by adjustment of one or more actuators.

[0055] Tractor/implement combination 10 includes a plurality of slave controllers for the sub-systems, in the form of microprocessors 40, 41, 42, 43 and 48.

[0056] External hydraulics control subsystem 40 controls the flow of hydraulic fluid to actuators, located externally of the tractor, that draw hydraulic power from the on-board hydraulic circuit of the tractor.

[0057] Certain parameters of the engine performance are controlled by means of an engine management system including microprocessor 41 that optimises engine performance in dependence on the throttle or engine governor settings input either by the tractor operator using suitable control members indicated schematically at 21, or from a programmable controller constituted as a further microprocessor also signified schematically by numeral 21 (described in greater detail in EP-A-0.838.141), located in the cab of the Figure 1 vehicle. The engine management system operates by adjusting various parameters, such as the metering volume of a fuel injection system, the timing of the fuel injection system, the boost pressure of a turbocharger (if present), the opening of engine valves and the opening of portions of the vehicle exhaust system, via suitable powered actuators such as solenoids.

[0058] Tractor 10 includes a semi-automatic transmission system in which the transmission ratio selected is determined by a slave controller in the form of microprocessor 42 acting on one or more solenoids to engage and disengage gear sets of the gearbox and/or gears of the transfer box, in dependence on the settings of a plurality of gear levers in the operator's cab 13 or in dependence on signals from microprocessor 21.

[0059] The Figure 1 embodiment includes hitch microprocessor 43 and plough control microprocessor 48. Microprocessor (slave controller) 43 controls the positions (ie. the heights) of the elements of the implement (three point) hitch 15. Again, the microprocessor 43 controls a number of actuators such as solenoids in dependence on the settings of eg. control levers in the operator's cab 13, on signals received from a further microprocessor 21, or, during carrying out of the method of the invention in dependence on its own programming.

[0060] Microprocessor 48 is in the embodiment shown in Figure 1 operatively connected to actuators, eg. respective hydraulic actuators, for adjusting the width of the plough; for inverting the plough at the end of each furrow; and for setting the plough working depth. Microprocessor 48 operates in dependence on signals received from microprocessor

21; from lever settings in cab 13; or according to its own programming. The plough adjustment actuators are known *per se* and are optional features of the tractor/implement combination.

[0061] Figure 1 also shows optional sensors 48a, 48b and 48c (illustrated schematically) whose purpose is the detection of the condition of the various plough adjustment actuators. Sensor 48a detects the state of a plough turnover actuator and hence indicates the orientation of the plough. Sensors 48b and 48c respectively detect the working depth and working width of the plough 60.

[0062] The microprocessors preferably are interconnected via a vehicle CAN-BUS 49, an extension 49a of which connects microprocessor 48 (and sensors 48a-48c) via a node 49b.

[0063] Cab 13 has mounted thereon an optional GPS position sensor 14 also connected to the CAN-BUS and hence to the microprocessors.

[0064] Plough 60 is in the embodiment shown a semi-mounted implement. The implement mounted actuators are described in more detail below. By "semi-mounted" is meant an implement the working depth of the front part 60a of which is adjusted by adjusting the height of the tractor implement hitch; and the height of a second part 60b, to the rear of part 60a, by an actuator 51 on the implement itself.

[0065] The use of a semi-mounted implement is not essential for carrying out the method of the first aspect of the invention which, as noted hereinabove, is suitable for controlling tractor/implement combinations including a wide variety of implements that need not be towed behind the tractor. However, the method of the third aspect of the invention is well suited to a tractor/implement combination in which the implement is semi-mounted, hence the exemplary implement shown in Figure 1.

[0066] As shown in Figure 1, part way along its length plough 60 includes a mid-axle mounted wheel 52, relative to the location of which the rear portion 60b of plough 60 is pivotable. Actuator 51 operates under the control of microprocessor 40 to effect such pivoting of plough rear portion 60b, in dependence on a control algorithm described in more detail hereinbelow in connection with a wheelslip control for the tractor/implement combination.

[0067] Referring now to Figure 2 there is shown a flow chart summarising the method steps by which a tractor/implement combination such as, but not limited to, the arrangement shown in Figure 1 may be operated in order to provide an accurate calibration indicator of the draught force of an implement such as plough 60. The steps of Figure 2 are normally carried out at the start of a period of operation, so that subsequent real time flywheel torque data acquired during use of the combination 10 may be corrected. However it is equally within the scope of the invention to carry out the calibration steps part way through a period of operation. This may be desirable eg. if the field conditions change part way through a ploughing operation.

[0068] The method of Figure 2 is preferably but not necessarily implemented by eg. microprocessor 21 of tractor/implement combination 10.

[0069] At the start of the method (step 70) the software implementing the method carries out any initialisation routines that are desirable. Such routines will in themselves be readily realisable within the knowledge of a worker skilled in the relevant art and are not described in detail herein.

[0070] When the method of the invention is carried out as part of a more extensive control method the initialisation of the software and of any programmable components connected thereto may be carried out as part of another method not described herein in detail.

[0071] At step 71, depending on the precise nature of the programming either the software or the tractor operator selects a typical engine speed for a data acquisition run. At step 72 the tractor operator selects an initial transmission ratio for a first data acquisition run. If desired the control software can prompt the operator to make the selection, eg. by displaying a message via eg. a configurable operator display in the operator's cab 13.

[0072] Following selection of the basic operating variables at steps 71 and 72 the tractor advances across a field surface with the implement such as plough 60 not engaging the ground. During this process the software acquires data from the flywheel torque sensor disclosed herein. Step 73 represents this part of the method.

[0073] Steps 74 and 75 respectively cause looping of the method to step 73 in the event of the data acquisition being unsuccessful or the data being corrupted (step 74); or in the event of further data being required in the currently selected transmission ratio (step 75). Clearly under such circumstances there is no need for the iteration to include selection of a further transmission ratio. One exemplary circumstance under which further data may be required arises when the tractor/implement combination operates in a sloping field.

[0074] If the field is generally flat with only isolated slopes, at ploughing speeds (approximately 4.5 - 8 km/h), the effect of the slopes is likely to be insignificant. However, if the field has substantially no flat areas (so that the tractor/implement combination is always travelling either uphill or downhill) it may be desirable to allow for the effect of this on the measured torque values.

[0075] One way of achieving this is for the tractor operator to carry out two data acquisition runs before commencing ploughing operations, ie. one with the tractor/implement combination 10 travelling uphill and one with it travelling downhill. The uphill and downhill calibration torque values can then be averaged and their average value used as the calibration flywheel torque value in Equation 1.

[0076] If the tractor/implement combination 10 includes an inclinometer whose output is input to the microprocessor 21 the latter can be programmed to provide an audible and/or visible warning to the tractor operator, if he attempts to commence a data acquisition run on sloping ground. The operator may then have the option of confirming or denying (eg. through menu screen choices) to the microprocessor that the field is substantially non-flat.

[0077] If the inclinometer is not present, the tractor operator may optionally select operation of step 75, eg. through use of a push button or a menu screen selection. The software will in either case "know" that the data acquisition run should consist of two parts (ie. uphill and downhill runs); and subsequent averaging. Step 75 represents these options schematically.

[0078] It is necessary for the method to include acquisition of data in a range of transmission ratios, corresponding to the ratios normally selected by the operator during normal use of the implement in question. Step 76 causes looping of the control program to repeat the method steps 72 to 75 for a suitable range of the tractor's transmission ratios. In other words, the transmission ratio may be shifted to a new value for each iteration until all the ratios in a chosen range have been used.

[0079] Once the data acquisition is complete for all the necessary ratios, at step 77 the software saves the resulting calibration data to a memory (eg. forming part of or otherwise associated with microprocessor 21).

[0080] The software includes an end routine 78 that may include *per se* known steps such as zeroing of registers and/or setting voltages to predictable values.

[0081] During subsequent operation of the tractor/implement combination 10 with the implement 60 engaged with the soil or with objects thereon the software acquires real time (instantaneous) torque data from the flywheel torque sensor. The stored calibration data corresponding to the transmission ratio and engine speed used during such operation are subtracted from the real time data. The result of the subtraction is then factored for the overall transmission ratio between the tractor flywheel and the driven ground engaging member (eg. a wheel or a caterpillar track); and also for the effective circumference of the said member. The subtraction and factoring occur in accordance with the following equation:

$$\text{Implement Draught (kN)} = \frac{\begin{bmatrix} \text{Instantaneous Flywheel} - \text{Calibration Flywheel} \\ \text{Torque (N.m)} \qquad\qquad \text{Torque (N.m)} \end{bmatrix} \times \text{PR}}{\text{Rear Tyre Rolling Radius (m)} \times 1000} \qquad \ldots(1)$$

Wherein :

PR = The tractor powertrain ratio, ie. the transmission and entire driveline ratio from the flywheel to the axle end;
Instantaneous Flywheel Torque = "Uncorrected Flywheel Torque"; and
Calibration Flywheel Torque = Transmission gear-specific flywheel torque value derived during a "Rolling Resistance" Calibration Procedure.

[0082] In the preferred embodiment, microprocessor 21 carries out the manipulation according to Equation 1.

[0083] The above factoring equation in practice relies on stored data corresponding to the overall transmission ratio and the effective circumference of the tractor tyre or track. These data may be stored in a memory eg. forming part of or associated with microprocessor 21. They may be preprogrammed by the tractor manufacturer; or programmed by the tractor operator eg. in the event of a change to tyres of different diameter.

[0084] The use of Equation 1 gives an actual draught force signal, that may be used to influence a control action. Thus the use of Equation 1 automatically compensates the actual flywheel torque value for the undesirable variables discussed herein. The control action typically involves adjusting one or more variable subsystems of the tractor/implement combination. These may include but are not limited to the following subsystems:

the selected tractor transmission ratio;
the implement working depth;
the implement working width;
the tractor engine governor setting; and
the tractor engine power output.

[0085] The control action in particular may include adjusting g. the working width or depth of a plough or shifting the tractor transmission. Various actuators, represented schematically by actuator 53 of Figure 1, may be operated for

such purposes.

[0086] Normally the calibration run described herein in relation to Figure 2 takes place with the engine governor at approximately a "full throttle" setting. However it is also within the scope of the invention for the calibration run to occur with the engine governor set at a "partly open throttle" setting. In the latter case the software may be programmed further to compensate the calibration draught force values, to generate values equivalent to a "full throttle" calibration run.

[0087] If at any time during operation of the tractor/implement combination (when the implement is semi-mounted as shown in Figure 1) the microprocessor 21 (or another of the microprocessors) detects slip of the driven wheels (or other ground engaging members), the working depth of the implement 60 may be raised. This is achieved by a simple control algorithm that operates hitch 15 and actuator 51 until wheelslip is no longer detected.

[0088] Elimination of wheelslip according to the method of the invention results in the advantages noted herein.

Claims

1. A method of controlling a tractor/implement combination (10), and **characterized in that** the method comprises the steps of:

   (i) while the tractor/implement combination (10) advances across a surface with a first tractor transmission ratio selected and the implement (60) disengaged from the surface, detecting the torque at the tractor engine flywheel, and generating a signal indicative thereof;
   (ii) storing in a memory the value of the signal as a calibration value associated with selection of the first transmission ratio;
   (iii) while the tractor/implement (10) advances across the said surface with a said transmission ratio selected, and with the implement engaging the said surface, detecting the torque at the tractor engine flywheel and generating an uncorrected torque signal indicative thereof;
   (iv) subtracting from the value of the uncorrected signal the stored calibration value associated with the selected said transmission ratio thereby to generate a corrected torque signal indicative of the draught of the implement (60); and
   (v) carrying out a control operation in dependence on the value of the corrected torque signal.

2. A method according to Claim 1 including, when the tractor includes more than one transmission ratio,

   (vi) shifting the tractor transmission ratio to a new ratio and repeating steps (i) and (ii) while the tractor/implement combination (10) advances with the new ratio selected, whereby to store a new calibration value associated with the new ratio.

3. A method according to Claim 2 including, when the tractor includes more than two transmission ratios,

   (vii) repeating step (vi) a plurality of times whereby to store a plurality of calibration values each respectively associated with a tractor transmission ratio.

4. A method according to any of Claims 1 to 3 wherein the corrected torque signal value is factored by an amount that is inversely proportional to the rolling radius of at least one driven, ground engaging driven member of the tractor.

5. A method according to any preceding claim wherein the corrected flywheel torque value is factored by an amount that is proportional to the transmission ratio of the tractor driveline between the tractor engine output and at least one driven, ground engaging member of the tractor.

6. A method according to any preceding claim wherein the control operation includes the steps of:

   (viii) calculating, from the corrected flywheel torque signal, the value of the draught force arising from engagement of the implement (60) with the surface; and
   (ix) adjusting or maintaining one or more variable subsystems of the tractor/implement combination (10) in order to maintain a generally constant implement working depth while the implement (60) engages the surface.

7. A method according to Claim 6 wherein the implement draught force value is calculated in accordance with the

formula:

$$\text{Implement Draught (kN)} = \frac{\begin{bmatrix}\text{Instantaneous Flywheel} - \text{Calibration Flywheel}\\ \text{Torque (N.m)} \qquad\qquad \text{Torque (N.m)}\end{bmatrix} \text{x PR}}{\text{Rear Tyre Rolling Radius (m)} \ \text{x} \ 1000}$$

8. A method according to Claim 6 or Claim 7 wherein the step (ix), of adjusting or maintaining one or more variable subsystems, includes adjusting or maintaining one or more of:

the selected tractor transmission ratio;
the implement working depth;
the implement working width;
the tractor engine governor setting; and
the tractor engine power output.

9. A method according to any preceding claim wherein the step (i) takes place with the tractor engine governor set at approximately a "full throttle" setting.

10. A method according to any preceding claim wherein the step (i) takes place with the tractor engine governor set at a "partly open throttle" setting, and wherein the method includes the step of :

(x) detecting the said governor setting and generating a signal indicative thereof; and further compensating the flywheel torque value in dependence on the governor setting signal to provide a value equivalent to use of a "full throttle" governor setting during operation of the tractor/implement combination (10) with the implement (60) disengaged from the said surface.

11. A method according to any preceding claim that is interrupted during shifts of the tractor transmission ratio.

12. A method according to any preceding claim, wherein the step (i) includes the sub-steps of:

(i.a) advancing the tractor/implement combination (10) in a first direction while detecting the torque at the tractor engine flywheel, and generating a "first direction" signal indicative thereof;
(i.b) advancing the tractor/implement combination (10) in a second direction while detecting the torque at the tractor engine flywheel, and generating a "second direction" signal indicative thereof; and
(i.c) averaging the "first direction" and "second direction" signals for storing at step (ii).

13. A method according to any preceding claim wherein the tractor/implement combination (10) includes an inclinometer capable of indicating whether the said combination is on inclined ground, the method including the sub-steps of generating a warning to the operator of the said combination (10) that it is on inclined ground; and permitting the operator to implement step (i) in a form modified to take account of the inclination of the ground.

14. A tractor/implement combination (10) comprising :

- a sensor for detecting the tractor engine flywheel torque and generating a signal indicative thereof;
- an actuator for selectively engaging the implement (60) with and disengaging it from a surface;
- a sensor for detecting the selected transmission ratio of the tractor and generating a signal indicative thereof;
- a memory; and
- a programmed processor (21, 40-43, 48); and

characterized in that the combination (10) is operable, under control of the processor :

(i) while the tractor/implement combination (10) advances across a surface with a first tractor transmission ratio selected and the implement (60) disengaged from the surface, to detect the torque at the tractor engine flywheel, and generating a signal indicative thereof;

(ii) to store in a memory the value of the signal as a calibration value associated with selection of the first transmission ratio;
(iii) to shift the tractor transmission ratio to a new ratio and repeat steps (i) and (ii) while the tractor/implement combination (10) advances with the new ratio selected, whereby to store a new calibration value associated with the new ratio;
(iv) to repeat step (iv) a plurality of times whereby to store a plurality of calibration values each respectively associated with a tractor transmission ratio;
(v) while the tractor/implement advances across the said surface with a said transmission ratio selected, and with the implement (60) engaging the said surface, to detect the torque at the tractor engine flywheel and generate an uncorrected torque signal indicative thereof;
(vi) to subtract from the value of the uncorrected signal the stored calibration value associated with the selected said transmission ratio thereby to generate a corrected torque signal indicative of the draught of the implement (10); and
(vii) to carry out a control operation in dependence on the value of the corrected torque signal.

15. A tractor/implement combination (10) according to Claim 14, wherein the memory includes stored therein tyre data indicative of the circumference of one or more driven ground engaging members of the tractor and wherein the processor is programmed to factor the value of the corrected flywheel torque signal by an amount proportional to the said circumference.

16. A tractor/implement combination (10) according to Claim 14 or Claim 15 including a sensor for detecting the selected tractor transmission ratio and generating a signal indicative thereof, the processor optionally or additionally being programmed to factor the value of the corrected flywheel torque signal by an amount proportional to the overall transmission ratio between the tractor engine flywheel and a said driven, ground engaging member.

17. A tractor/implement combination (10) according to any of Claims 14 to 16 wherein the processor is programmed to carry out a method according to any of Claims 1 to 13.

18. A tractor/implement combination (10) according to any of Claims 14 to 17 including an actuator for increasing and decreasing the working depth of the implement (60) in dependence on an output of the processor.

19. A tractor/implement combination (10) according to any of Claims 13 to 18 including an actuator for shifting the tractor transmission in dependence on an output of the processor.

20. A tractor/implement combination (10) according to Claim 18 or Claim 19 including a plurality of further sensors for detecting a plurality of further variables of the said combination and generating further signals indicative thereof; and wherein the said processor is programmed to optimise the workrate of the tractor, in dependence on the values of the said further signals, by operating a said actuator.

21. A tractor/implement combination (10) according to Claim 20 wherein the memory includes stored therein a steady state reference model of the outputs of the sensors and the further sensors, the processor being programmed to employ the reference model to optimise the workrate of the combination.

22. A tractor/implement combination (10) according to any of Claims 14 to 21 including an inclinometer capable of indicating whether the said combination is on inclined ground and an indicator for generating a warning to the operator, of the said combination (10), that it is on inclined ground.

23. A method of controlling tractor wheelslip in a tractor/implement combination (10) in which a tractor three point hitch (15) at least partly supports the implement (60) and in which the implement (60) is semi-mounted by means of a mounting (52) remote from the three point hitch (15), and
characterized in that the method includes the steps of:

(i) setting a wheelslip limit corresponding to a desired maximum degree of wheelslip;
(ii) detecting an instantaneously prevailing degree of wheelslip;
when the detected degree of wheelslip equals or exceeds the wheelslip limit, (iii) raising a first part (60a) of the implement by raising the three point hitch; and
(iv) raising a second part (60b) of the implement relative to the said remote mounting (52), until the detected degree of wheelslip is less than the wheelslip limit.

24. A method according to Claim 23 wherein the step (iv) of raising the second part (60b) of the implement occurs according to an open loop control algorithm.

25. A method according to Claim 24 wherein the step (iv) includes raising the second part (60b) of the implement in a plurality of increments each separated from one another by a time delay.

26. A method according to any of Claims 23 to 25 wherein the said remote mounting (52) includes a mid-axle mounted wheel relative to which a remote part (60b) of the implement is moveably secured by a mechanism including a length-adjustable actuator (51); and the step of raising the said mounting includes adjusting the length of the said actuator (51).

27. A method according to any of Claims 23 to 26 wherein the method includes the further step of:

(v) lowering the first part (60a) of the implement by lowering the three point hitch (15); and lowering the second part (60b) of the implement relative to the remote mounting (52).

28. A method according to Claim 27 when dependent from Claim 23, wherein the length-adjustable actuator (51) includes a fluid actuator having a spool valve, and wherein the step of lowering the second portion (60b) includes exhausting fluid from the actuator via the spool valve.

29. A tractor/implement combination (10) wherein the tractor three point hitch (15) supports part of the implement; and wherein the implement is semi-mounted by means of a mounting (52) remote from the three point hitch (15), the combination including:

a wheelslip detector;
an actuator for raising and lowering the three point hitch;
an actuator (51) for raising and lowering a part of the implement relative to the said remote mounting (52);
a processor capable of generating adjustment signals for causing adjustment of the hitch height and the actuator height; and
a memory capable of storing therein a wheelslip limit value, the processor being programmed to carry out a method according to any of Claims 23 to 28 by adjusting the hitch height and the actuator height.

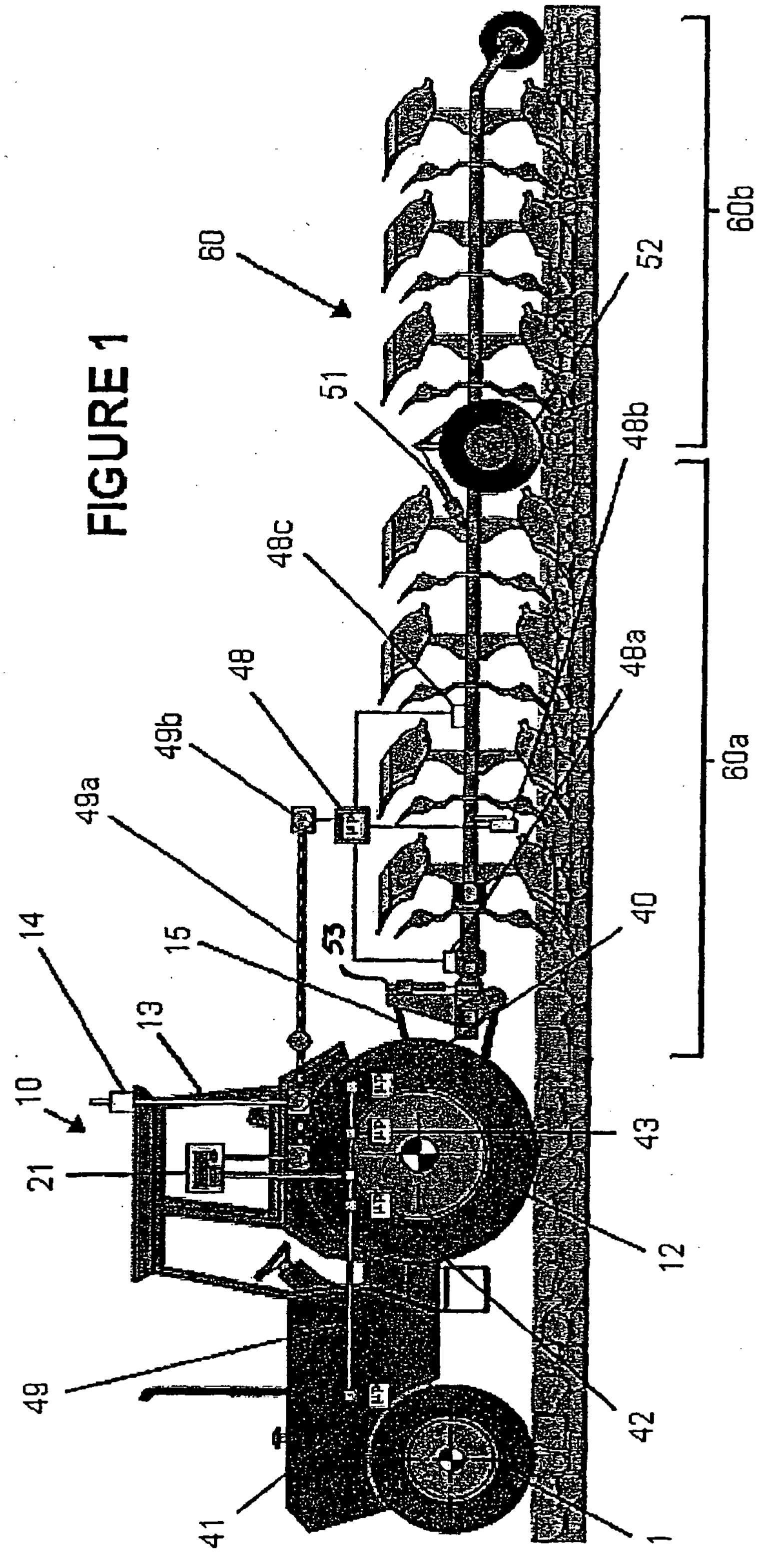
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FIGURE 1

Rolling Resistance Calibration Procedure

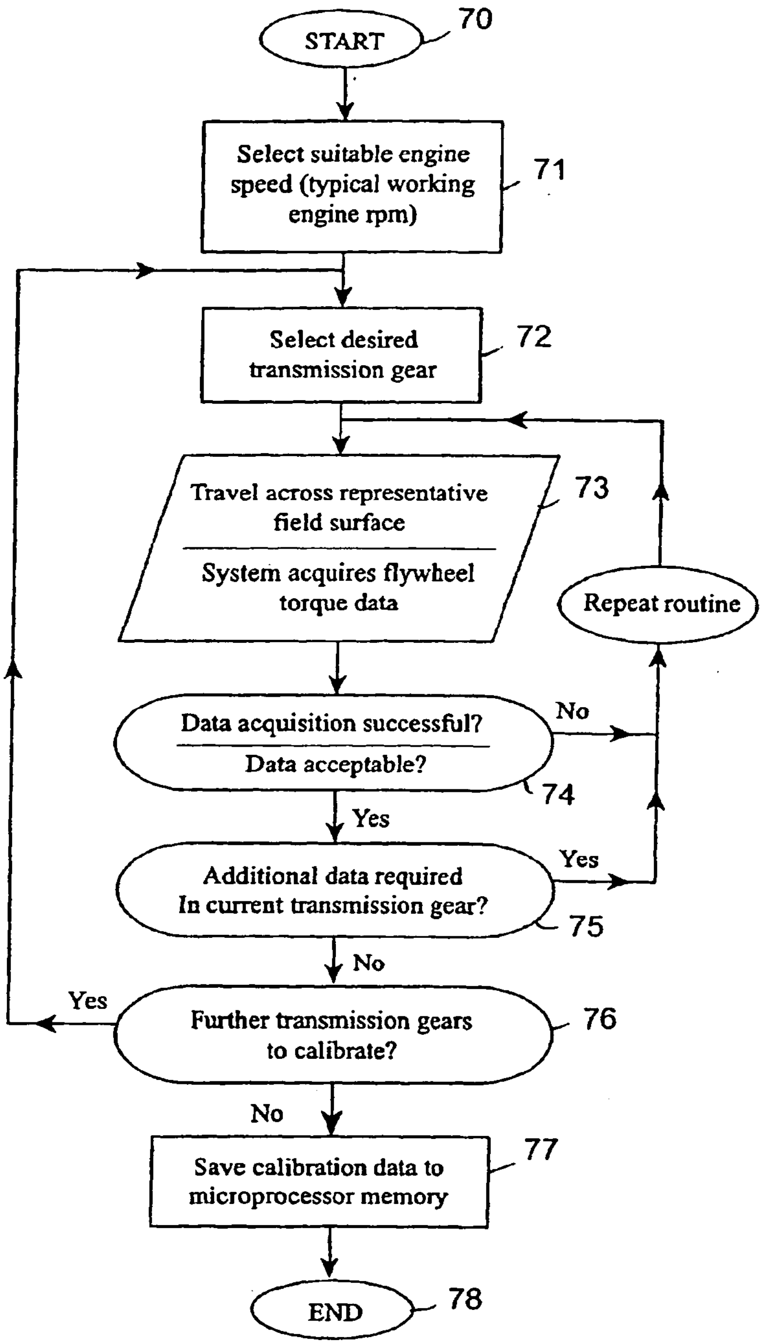

FIGURE 2